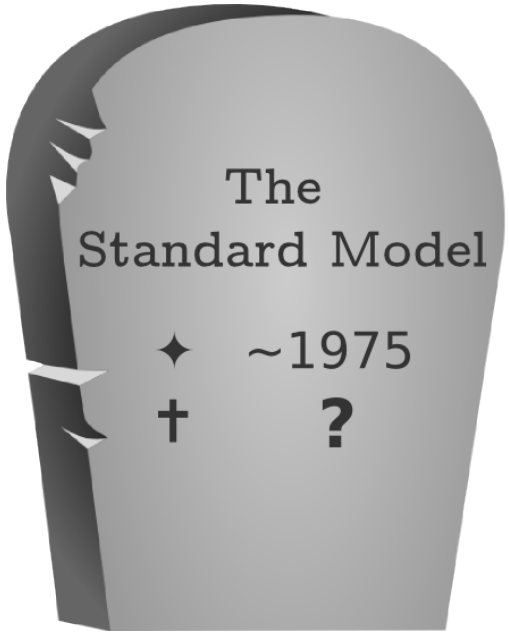
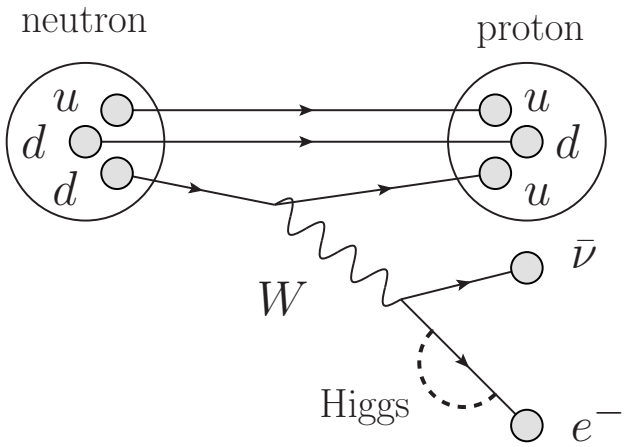
A **New Window** for **New Physics** in B_s decays to two muons



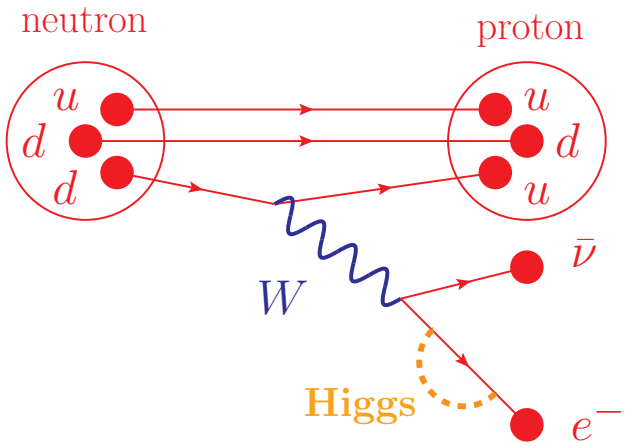
Rob Knegjens

New Physics beyond the **Standard Model**?



New Physics beyond the **Standard Model**?

- Matter: **spin** $\frac{1}{2}$
- Force carriers: **spin** 1
- Higgs boson: **spin** 0



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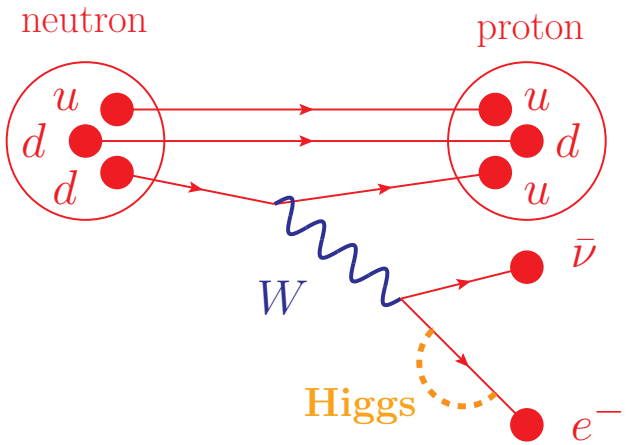

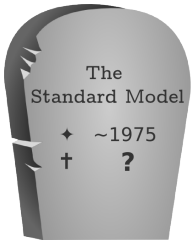

- Dark Matter
- Fine-tuning
- Gravity

Expect **new, heavy** particles!

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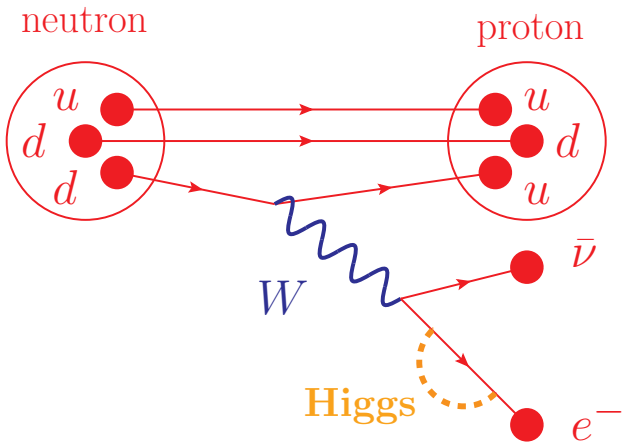

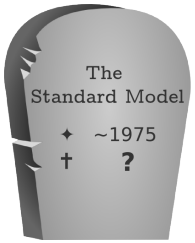

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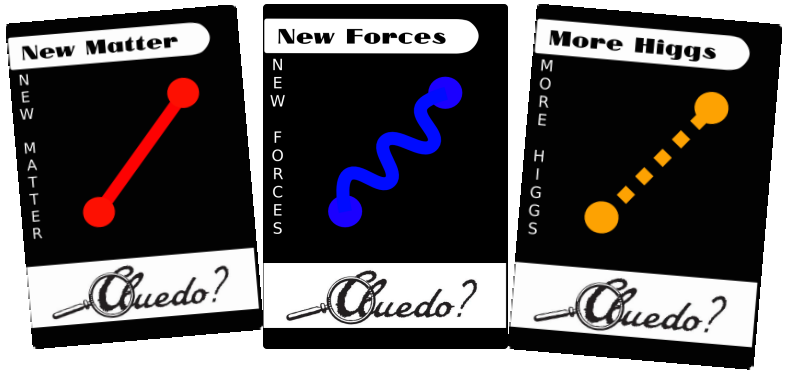
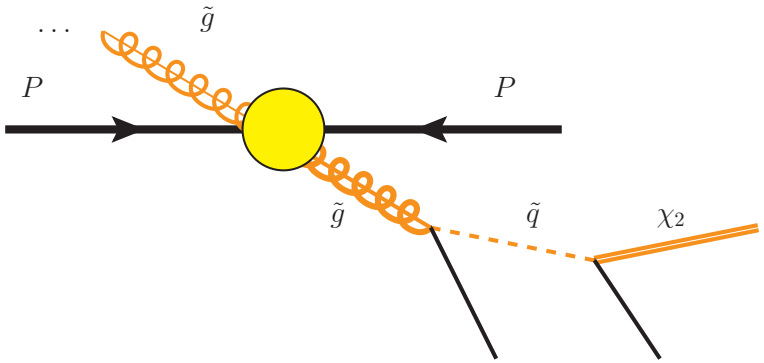


What will **kill** the Standard Model?

Clue : **spin structure** of New Physics?

The **search** for New Physics

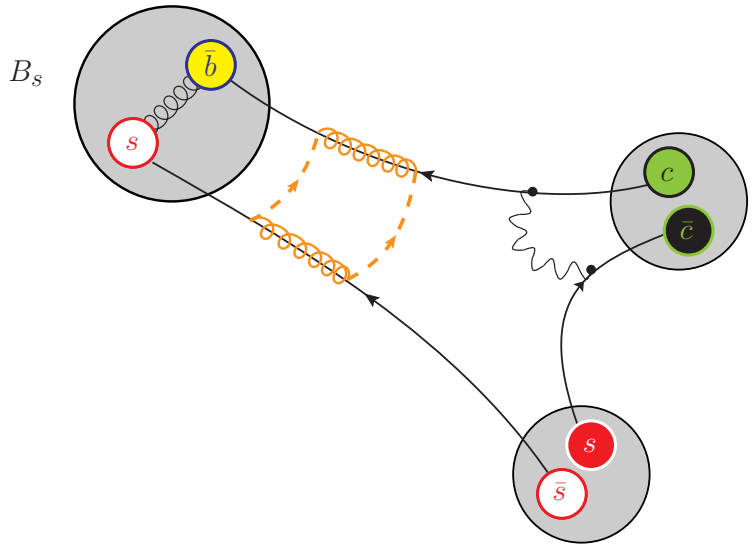


Direct searches

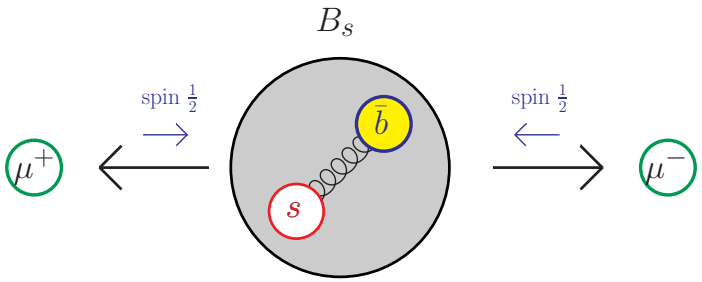
"The high energy frontier"

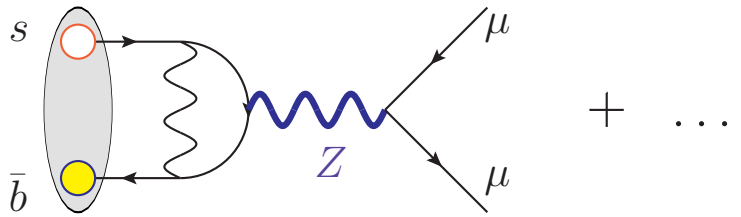
Indirect searches

"The precision frontier"



The (famous) **Rare Decay** $B_s \to \mu^+\mu^-$



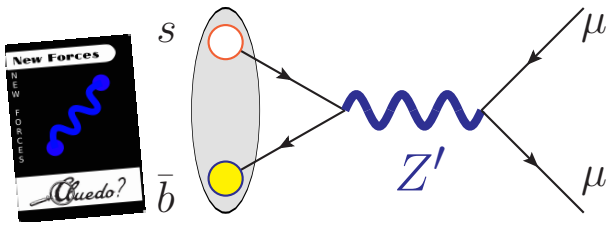


Probability **suppressed** in Standard Model (SM):

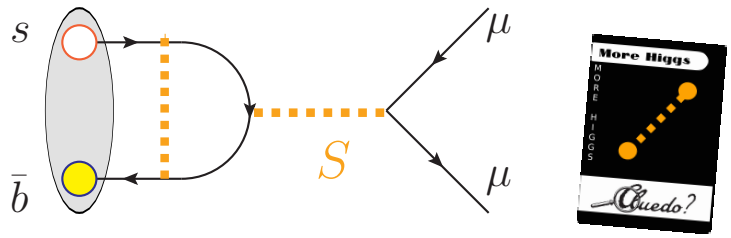
$$\text{Branching Ratio}(B_s \to \mu^+\mu^-)_{\text{SM}} = 3.23 \pm 0.27 \times 10^{-9}$$

Sensitive to New Physics:

New Force carrier? (spin 1)

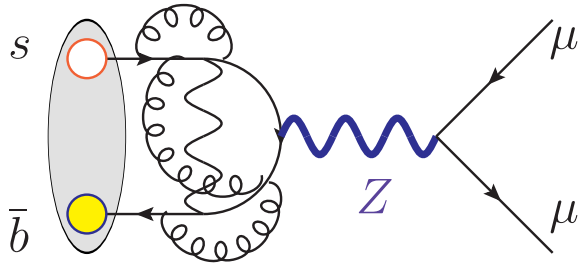


More Higgs bosons? (spin 0)



Would be great if we could **distinguish** these. . . !

A Model-independent approach



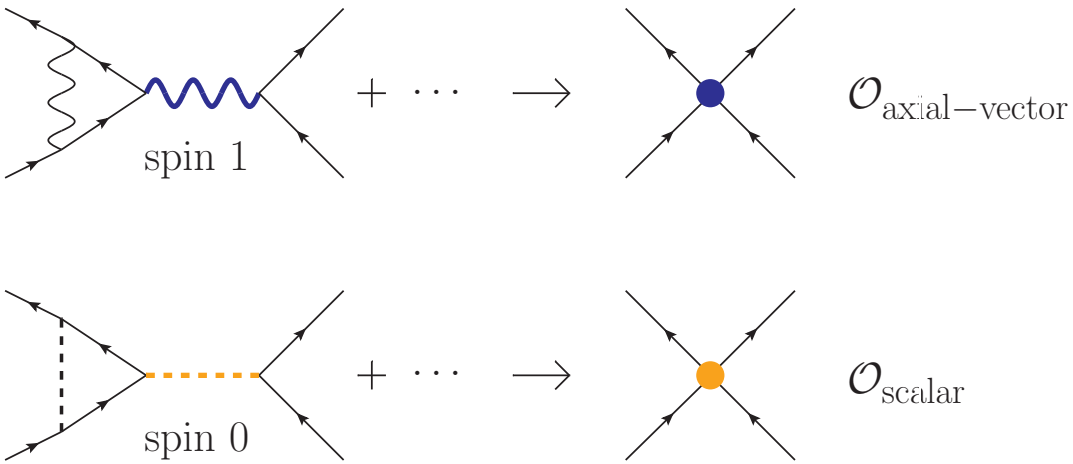
Mesons decay at "low" energy

$E \sim \mathrm{GeV}$

Strong force **troublesome**

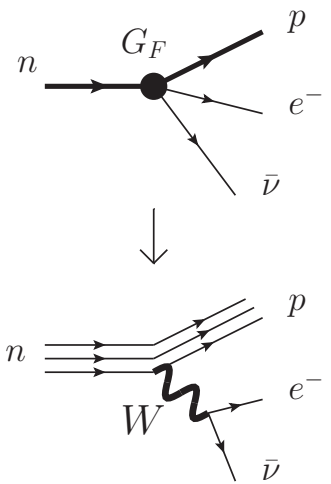
Effective theory : $\langle \mu^+\mu^- | \mathcal{H}_{\mathrm{eff}} | B_s \rangle = \sum_i \underbrace{C_i(\geq E)}_{\text{coupling}} \cdot \underbrace{\langle \mathcal{O}_i(\leq E) \rangle}_{\text{operator}}$

All operators with unique **spin structure**:



Example:

Fermi-interaction:



The $B_s \to \mu^+\mu^-$ Branching Ratio

Define for convenience:

$$\begin{array}{rcl} C_{\text{scalar}} & \in & S \\ C_{\text{axial-vector}}, \ \ldots & \in & P \end{array} \quad \xrightarrow{\text{Standard Model}} \quad \begin{array}{l} S_{\text{SM}} = 0 \\ P_{\text{SM}} = 1 \end{array}$$

$$\text{BR}(B_s \to \mu^+\mu^-) = 3.2 \times 10^{-9} \times (|P|^2 + |S|^2)$$

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$$\in [1.1,\, 6.4] \times 10^{-9} \quad @\,95\%\text{C.L (LHCb)}$$

LHCb, 1211.2674 [hep-ex] (2012)

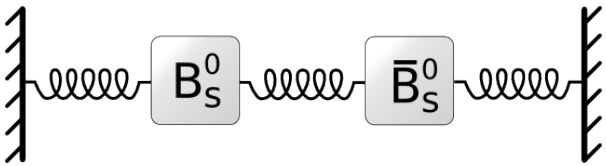
No dramatic **New Physics**, maybe moderate?

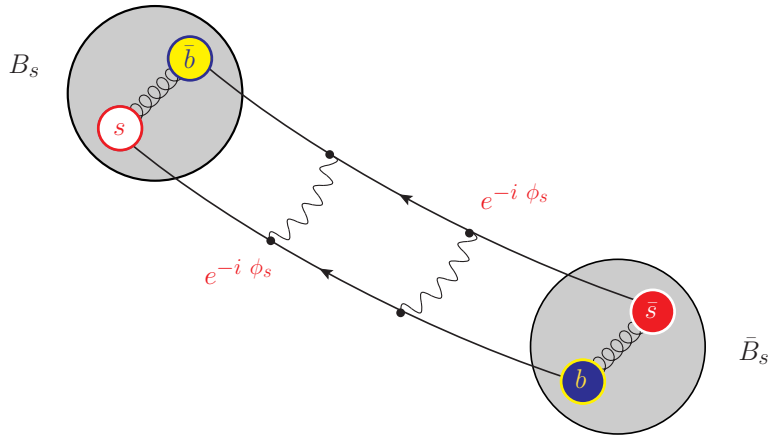
How to **disentangle** S from P?

Decay rate asymmetry?

B_s meson system:

$$B_s^0 \supset s\,\bar{b} \quad \overset{\text{mix}}{\longleftrightarrow} \quad \bar{B}_s^0 \supset \bar{s}\,b$$





$$\text{"Normal modes"} \Longrightarrow \begin{cases} |B_{s,\mathrm{H}}\rangle = \frac{1}{\sqrt{2}}\left(|B_s^0\rangle - e^{-i\phi_s}|\bar{B}_s^0\rangle\right) \\ |B_{s,\mathrm{L}}\rangle = \frac{1}{\sqrt{2}}\left(|B_s^0\rangle + e^{-i\phi_s}|\bar{B}_s^0\rangle\right) \end{cases} \quad \text{(mass eigenstates)}$$

$B_{s,\mathrm{H}} \to \mu^+\mu^-$ **dominant** in Standard Model (SM):

$$\Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-) \propto \cancel{|S|^2}^{\,0 \text{ in SM}} + \cancel{\text{CP violation}}^{\,\approx 0 \text{ in SM}}$$

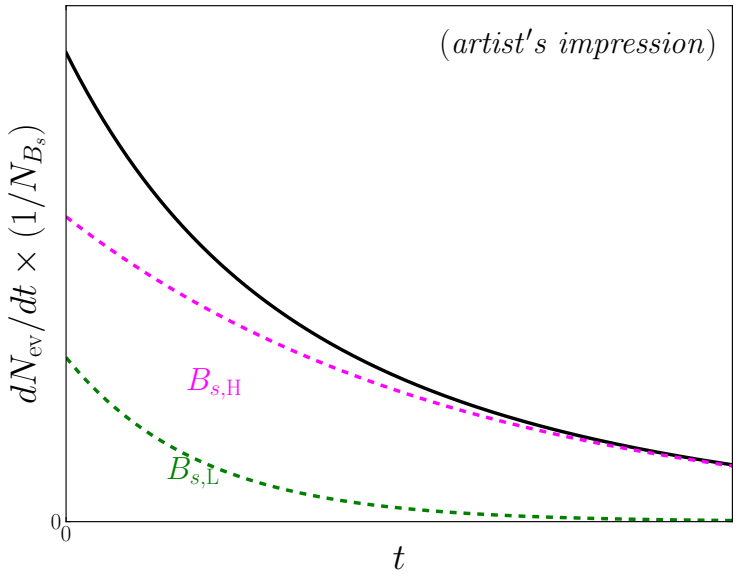
Can we **distinguish** $B_{s,\mathrm{H}}$ from $B_{s,\mathrm{L}}$...?

Lifetime difference

Lifetime difference recently observed:

$$\frac{\tau_{\mathrm{H}} - \tau_{\mathrm{L}}}{\tau_{\mathrm{H}} + \tau_{\mathrm{L}}} = 9\%$$

LHCb, arXiv:1112.3183



Perform fit of time-dependent $B_s \to \mu^+\mu^-$ event rate:

$$\frac{1}{N_{B_s}}\frac{dN_{ev}}{dt} \propto e^{-t/\tau_{\mathrm{H}}}(1 + \mathcal{A}_{\Delta\Gamma}) + e^{-t/\tau_{\mathrm{L}}}(1 - \mathcal{A}_{\Delta\Gamma})$$

Give us **second constraint/clue**!

$$\boxed{\mathcal{A}_{\Delta\Gamma} = \frac{\Gamma(B_{s,\mathrm{H}} \to \mu^+\mu^-) - \Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-)}{\Gamma(B_{s,\mathrm{H}} \to \mu^+\mu^-) - \Gamma(B_{s,\mathrm{L}} \to \mu^+\mu^-)}} \xrightarrow{SM} 1$$

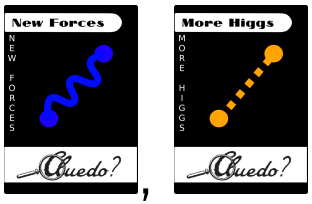
Classifying New Physics in $B_s \to \mu^+\mu^-$

2 constraints/clues!

$$\boxed{\mathrm{BR} \propto |P|^2 + |S|^2}$$

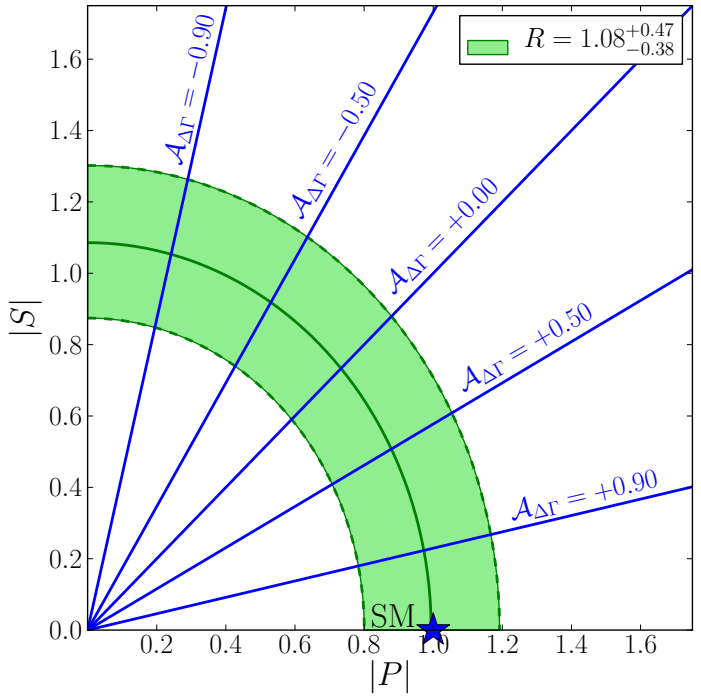
$$\boxed{\mathcal{A}_{\Delta\Gamma} = \frac{|P|^2 \cos(2\varphi_P - \phi_s^{\mathrm{NP}}) - |S|^2 \cos(2\varphi_S - \phi_s^{\mathrm{NP}})}{|P|^2 + |S|^2}}$$

Depend on 2+ **parameters:**



, , ...

Closer to identifying **nature** of **New Physics!**

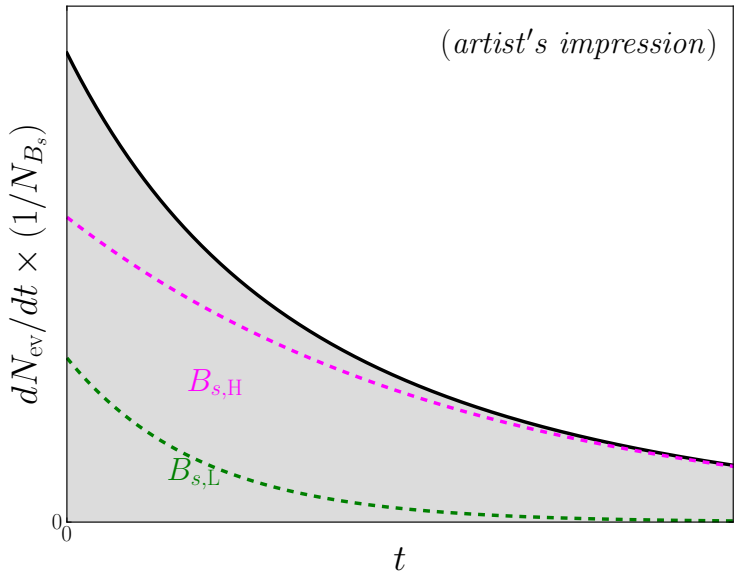


K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, A. Pellegrino, N. Tuning, Phys.Rev.Lett 109 (2012)

Technical aside: Branching Ratios

Lifetime difference affects all B_s Branching Ratios!

$$\mathrm{BR}(B_s \to f)_{\text{exp}} = \int \frac{1}{N_{B_s}} \frac{dN_e}{dt} dt$$
$$= \frac{1}{2}\Big[\mathrm{BR}(B_{s,\mathrm{H}} \to f) + \mathrm{BR}(B_{s,\mathrm{L}} \to f)\Big]$$



versus

$$\mathrm{BR}(B_s \to f)_{\text{theory}} = \left(\frac{\tau_{\mathrm{L}}}{\tau_{\mathrm{H}} + \tau_{\mathrm{L}}}\right) \mathrm{BR}(B_{s,\mathrm{H}} \to f) + \left(\frac{\tau_{\mathrm{H}}}{\tau_{\mathrm{H}} + \tau_{\mathrm{L}}}\right) \mathrm{BR}(B_{s,\mathrm{L}} \to f)$$

Dictionary : $\mathrm{BR}(B_s \to f)_{\text{theory}} \to \mathrm{BR}(B_s \to f)_{\text{theory}} \left[1 + \mathcal{A}_{\Delta\Gamma} \left(\frac{\tau_{\mathrm{H}} - \tau_{\mathrm{L}}}{\tau_{\mathrm{H}} + \tau_{\mathrm{L}}}\right) + \ldots\right]$

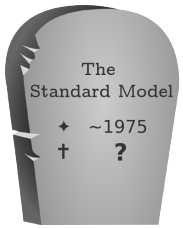
e.g. $\mathrm{BR}(B_s \to \mu^+\mu^-)\big|^{\mathrm{SM}}_{\mathrm{theo}} = 3.5 \times 10^{-9} \uparrow 10\%$

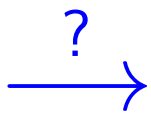
K. Bruyn, R. Fleischer, RK, P. Koppenburg, M. Merk, N. Tuning, Phys.Rev.D 86 (2012)

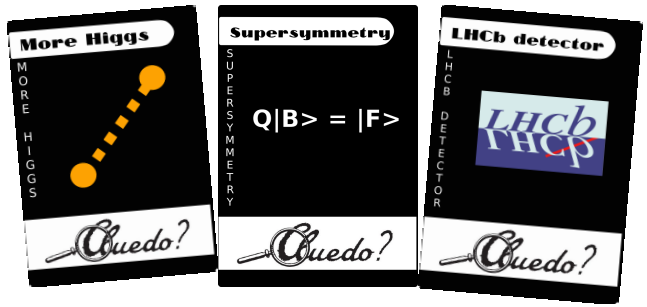
Outlook

- $\mathcal{A}_{\Delta\Gamma}$ measurement: high-luminosity **upgrades** of LHCb and CMS?
- **Flavour-tagging** (distinguishing B_s^0 from $\bar{B}_s^0$ before decay) would give additional sensitivity
- Look at **models of New Physics** where $\mathcal{A}_{\Delta\Gamma}$ has big impact

Look forward to **future measurements** of $\mathrm{B_s} \to \mu^+\mu^-$!

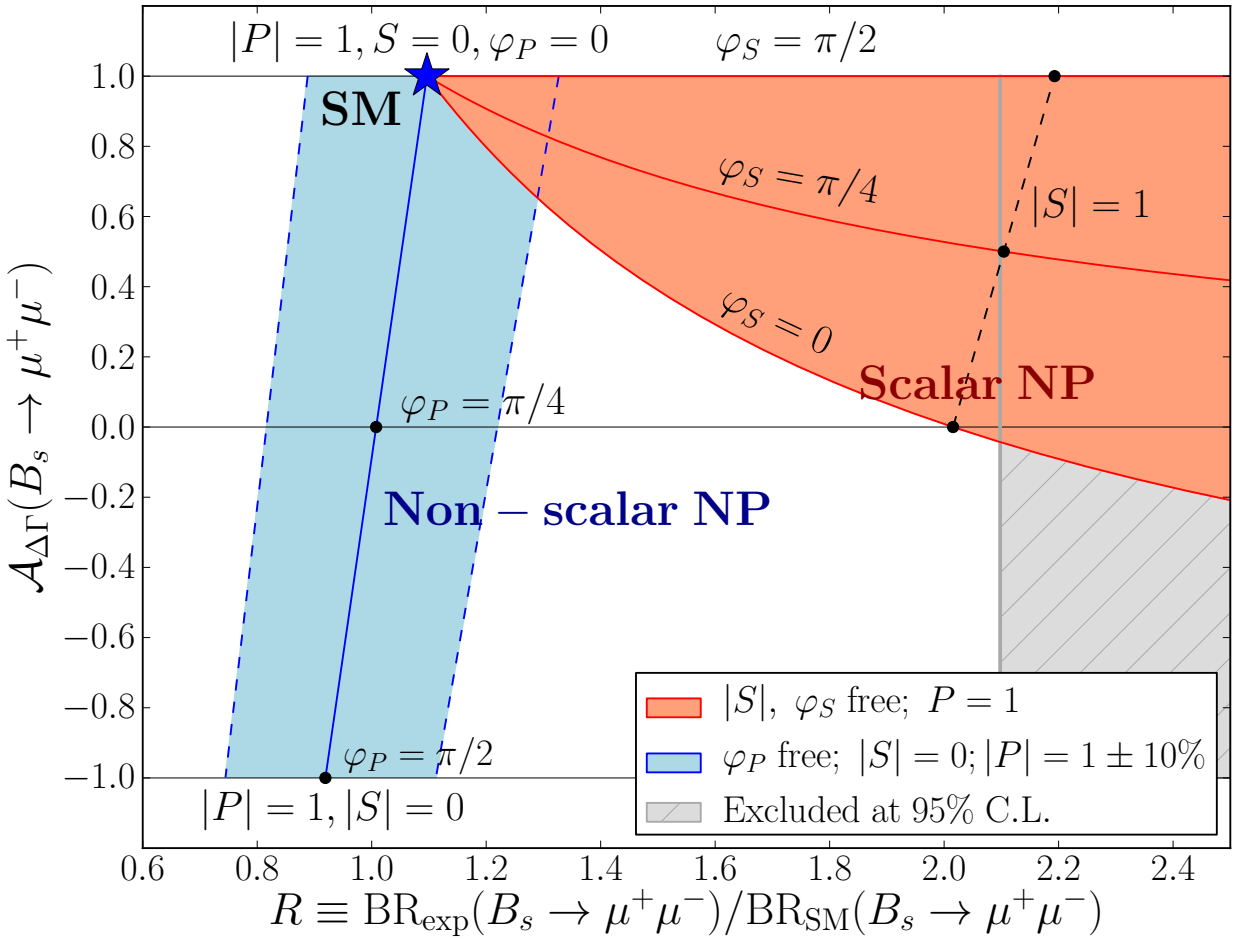






Backup slides

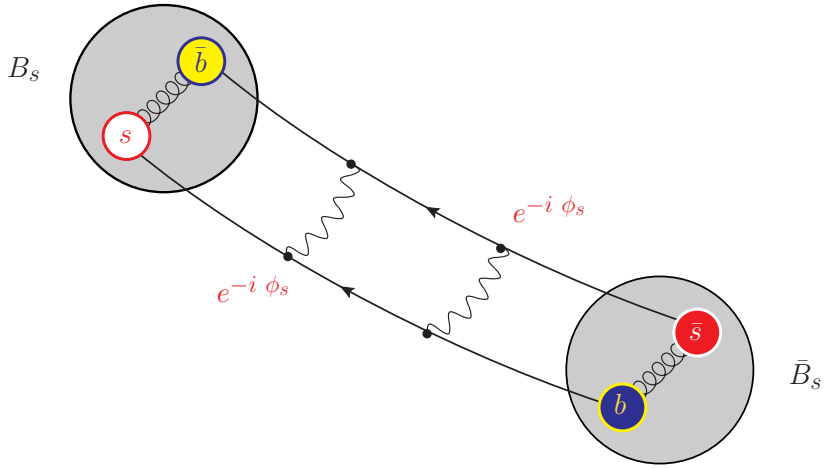
Including CP violating phases



Decay rate asymmetries?

B_s meson system:

$B_s^0 \ni s\,\bar{b}, \qquad \bar{B}_s^0 \ni \bar{s}\,b$



Scalar operator gives asymmetry in decay rates:

$$\Gamma(B_s^0 \to \mu_L^+ \mu_L^-) \propto |P - S|^2 \propto \Gamma(\bar{B}_s^0 \to \mu_R^+ \mu_R^-)$$
$$\Gamma(\bar{B}_s^0 \to \mu_L^+ \mu_L^-) \propto |P + S|^2 \propto \Gamma(B_s^0 \to \mu_R^+ \mu_R^-)$$

But measuring muon polarization very challenging...

$$\sum_{\lambda \in \{L,R\}} \Gamma(B_s^0 \to \mu_\lambda^+ \mu_\lambda^-) - \sum_{\lambda \in \{L,R\}} \Gamma(\bar{B}_s^0 \to \mu_\lambda^+ \mu_\lambda^-) = 0$$

...and distinguishing B_s^0 from $\bar{B}_s^0$ also challenging